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Method for Quantitatively Determining the Width of a Soft Zone Area of a Partially Hardenened Workpiece

Technical Background

The present invention relates to a method for quantitatively determining the width of a soft zone area of a partially hardened metallic workpiece having at least one hardened and one unhardened area by means of at least one multifrequency eddy current sensor.

Prior Art

Components that often used in automatic transmissions are so-called planetary transmissions, whose gear teeth continuously intermesh. Despite the multiplicity of differently designed planetary transmissions, all these type of transmissions have in common that at least one gear which is designed as a planet wheel intermeshes with a centrally placed sun wheel and a peripherally running ring gear wheel. Usually so-called planet wheel bolts run through the center of the planet wheels, extending on both sides. In order to produce such type planet wheel bolts, solid or hollow cylindrical metallic rods are cut to the desired length. In order to improve the solidity of the material, the cut cylindrical pieces are subjected to a hardening process. For subsequent processing of the front ends of the individual cylindrical workpieces, the respective front ends are not subjected to the hardening process. Used for hardening the workpiece is the as such known induction hardening with which it is possible to effectively heat practically the entire cylindrical workpiece with the exception of the areas at the front ends of the workpiece. The front end areas of the workpiece that should intentionally not be subjected to the hardening process have, depending on the respective size of the workpiece, an axial extension, respectively a width, of a few millimeters, preferably between 1.5 mm and 2.5 mm.

The front ends of cylindrical workpieces partially hardened in the aforedescribed manner are then processed usually by means of a material-removing process. It is easy to understand that if the workpiece were fully hardened it would be much more difficult to carry out the finishing step and would subject the removal tool to much more wear. For this reason, there is particular interest in partially hardening under the aforedescribed conditions partially hardened, cylindrical workpieces present as half-finished products in order to ensure that the front ends of the partially hardened workpieces represent so-called "soft zone areas", that remain unhardened.

Hitherto, in order to control the quality of the partially hardened half-finished products, as such known control methods, such as for example visual inspection of the front soft zone areas, which requires a schooled look in order to be able to distinguish the hardened area of the workpiece from the unhardened one. At a suited angle of vision and under suited lighting conditions, light reflects in a minimally different manner, respectively scatters, on the surface of the soft zone area than on the surface region of the hardened workpiece. Undoubtedly, this control method is expensive and time consuming. Moreover the control staff is prone to become tired; thus control reliability cannot be ensured in the desired manner.

In order to avoid employing staff, there is one known optical control measuring method known which permits detecting the color differences due to which the soft zone area differs from the hardened zone.

In addition to optical methods, electro-magnetic methods are known, for example, the multifrequency eddy current method described, for example in DE 36 20 491 C2. The eddy current principle detects surface flaws as well as differences in the microstructure from irregularities in the induced eddy currents. Scanning probes or encircling probes induce these eddy currents and simultaneously measure the electro-magnetic fields generated by these eddy currents. Evaluation of the measuring signals obtained by means of the multifrequency eddy current described in the preceding printed publication is based on elliptical evaluation in the impedance plane using a multiplicity of measuring frequencies and permits a solely qualitative finding of the to-be-examined workpiece. With the proposed evaluation methods, it is not possible to state the absolute size of the soft zone areas present.

Also known are so-called magnetic Barkhausen noise methods with which high-frequency Barkhausen oscillations are induced into a to-be-examined workpiece by means of dynamic reverse magnetization processes. The high-frequency Barkhausen oscillation can be detected by a magnet-inductive receiver. The intensity of the Barkhausen noise is much more intense in the soft zone area than in the hardened zone area so that it is possible to discern and measure the differences in the two workpiece areas. A disadvantage, however, is the necessity of an excitation yoke and the great sensitivity to disturbing outside influences, which permits industrial use of such a type of method only to a limited extent.

DE 43 10 894 A1 describes a method and a testing probe for non-destructive examination of surfaces of electrically conductive workpieces. The testing probe described in the printed publication should enable obtaining information about the hardness, thickness and state of the microstructure of an electrically conductive workpiece. Due to the interaction of the magnetic alternating field acting in the workpiece and the measurable voltage induced in the testing coil of the multifrequency alternating field sensor. With the aid of a multifrequency eddy current sensor, information can be gained about at least one material property of the examined surface in the area of the penetration depth of the magnetic alternating field. In particular, the prior art method for determining the course of a hardness profile along a to-be-examined electrically conductive workpiece serves to determine the thickness of the respective surface layers on the workpiece.

Summary of the Invention

The object of the present invention is to provide a method for determining quantitatively the size of a soft zone area of a partially hardened metallic workpiece, which has at least one hardened and one unhardened area, using at least one multifrequency eddy current sensor, in such a manner permitting quick and exact quantitative determination of the soft zone area of a partially hardened workpiece, preferably a planet wheel bolt present in the form of a half product, by means of simple and cost-effective means. It should be possible to use the method on an

industrial scale and in inline operation, i.e. on a continuously or pulsed operated production line.

The quantitative measurement with which the soft zone area should be measured should be sufficiently exact for example with a precision of ±0.3 mm.

The solution of the object on which the present invention is based is set forth in claim 1. Features which further develop the inventive idea are the subject matter of the subordinate claims and can be drawn from the further description with reference to the preferred embodiment.

According to the invention, a method according to the generic part of claim 1 is developed in that a workpiece is moved respectively led individually relative to a multifrequency current eddy sensor in such a manner that a eddy current field generated by the multifrequency eddy current sensor interacts contactlessly with the workpiece in a spatially delimited manner, generates therein eddy currents, which, in turn,

generate a measuring signal in the multifrequency eddy current sensor, with the delimited eddy current field having a greatest extension oriented in longitudinal direction to the surface of the workpiece, which extension is greater than a maximum extension of the soft zone area in longitudinal direction to the surface of the workpiece.

With the aforementioned measuring preconditions, in a first step the aim is to generate calibrated data obtained from a number n of workpieces which preferably are from the group of the to-be-measured workpieces. Assuming a predetermined standard size of the width of the soft zone, i.e. the desired size of an extension oriented in longitudinal direction to the surface of the workpiece, the measuring signals of the n workpieces are used to plot a calibration curve. Then using the calibration curve obtained in this manner, the subsequently conveyed workpieces are measured in the same manner. Based on the calibration curve, the obtained measuring signals can now each be assigned to absolute soft zone widths.

The invented method is therefore distinguished by, in a first step, dynamic calibration, i.e. correlating the measuring signals with desired sizes in the form of soft zone widths present as absolute values, occurring while the workpieces are being conveyed to the measuring sensor in a continuously pulsed manner. In a second step, the soft zone widths of all the subsequent workpieces conveyed to the multifrequency measuring sensor are then quantitatively determined with high precision. The invented method, thus, can be used on industrial production lines without influencing the flow of the workpieces on the conveyer belt as the conducted quality control is completely contactless.

The invented method is described in the following with reference to measuring planet wheel bolts as half-finished products, which as mentioned in the preceding have a cylindrical shape and two soft zone areas provided on their front ends. The front end soft zone areas are separated from each other by a hardened middle area which is dimensioned longer in the axial direction.

Of course, the invented method can also be applied to alternative partially hardened workpieces where information about an exact spatial extension of hardened or not hardened workpiece areas is relevant.

Brief Description of the Invention

The present invention is made more apparent by way of example in the following without the intention of limiting the overall inventive idea using preferred embodiments with reference to the accompanying drawings.

Fig. 1 shows a schematic representation of a partially hardened planet wheel bolt with a multifrequency eddy current sensor, and

Fig. 2 shows a qualitative, diagrammatic representation of an amplitude locus curve for determining a defined relative position between the to-be-measured workpiece and the multifrequency sensor.

Ways to Carry Out the Invention, Commercial Applicability

Fig. 1 shows very schematically a planet wheel bolt 1 which usually is made of a solid metallic material and has, by means of induction hardening, a hardened zone 2 in the middle region of the bolt 1. Figure 1 shows both a lateral as well as a front view of the measuring situation. Adjunct to the hardened zone 2 on both sides are unhardened areas, the so-called soft zone areas 3, which terminate with the front ends of the planet wheel bolt 1. Depending on the shape and dimensioning of the planet wheel bolt 1, the soft zone areas 3 usually have an axial longitudinal extension, i.e. a soft zone width b ranging between 1.5 mm and 2.5 mm.

In order to exactly measure the soft zone width b, knowledge of which is important for subsequent processing processes, as a result of which the planet wheel bolt present as a half-finished product assumes an outer shape, which for example is determined by selective material removal inside the soft zone area 3, the multifrequency eddy current sensor 4 is moved parallel to the longitudinal extension of the planet wheel bolt 1 at a distance thereof in the direction depicted in fig. 1. In an industrial application, it is advantageous if the multifrequency eddy current sensor 4 rests in place and the to-be-measured workpieces are conveyed singly to the sensor area along a conveyor path.

The multifrequency eddy current sensor 4 possesses an effective width oriented in the direction of movement (see arrow). The effective width is larger than the axial extension of the soft zone width 3 so that it is ensured that with suited positioning relative to the planet wheel bolt 2, the eddy current field generated by the multifrequency eddy current sensor 4 extends completely over the soft zone area 3.

For exact determination of the soft zone width b, a measurement constellation has to be created in which the multifrequency eddy current sensor 4 extends completely over the soft zone 3, with the eddy current field generated by the multifrequency eddy current sensor 4 simultaneously being able

to penetrate a partial area of the hardened zone adjacent to the soft zone 3. Fig. 1 shows such a type measurement constellation.

As the relative movement between the multifrequency eddy current sensor 4 and the planet wheel bolt 1 occurs with a constant velocity, the time point, respectively that measurement constellation as shown in fig. 1, has to be determined in which measurement of the sought soft zone width b is possible.

Usually, detection of the measuring signals by means of the multifrequency eddy current sensor 4 occurs in a pulsed manner so that a multiplicity of single measuring signals are detected while the eddy current measuring sensor 4 moves over the entire length of the planet wheel bolt 1. The multifrequency eddy current sensor 4 is operated in an advantageous manner with 4 different test frequencies so that ultimately 4 measuring signals are obtained per measuring point. For further evaluation in the complex impedance level, the measuring signals are each split into real and imaginary parts according to phase and amplitude. Thus there are 8 different measuring signal components at disposal for signal evaluation per measuring point.

From the measuring signals obtained during the relative movement of the multifrequency eddy current sensor 4 along the surface in axial direction to the planet wheel bolt 1, the obtained measuring signals can be represented in the form of an amplitude locus curve for each measuring frequency. The amplitude locus curve (X-axis corresponding to the locus coordinate, the amplitude levels of the measuring signal are plotted along the Y-axis) shown in fig. 2 permits exact extraction of that measuring signal obtained in the aforedescribed measuring constellation required for measuring the soft zone width b. The determination, respectively selection, of the measuring signal relevant for measurement evaluation from the amplitude locus curve occurs based on empirically gained data if the relative velocity between the sensor and the workpiece is sufficiently constant.

In the same manner as the measuring signal is extracted for determining the width of the soft zone shown in fig. 1 as the left soft zone 3, a certain measuring signal for

determining the width of the soft zone can also be derived for the right soft zone 3 in fig 1.

The preceding description shows that the relative spatial position between the multifrequency eddy current sensor 4 and the to-be-measured planet wheel bolt 1 can be determined contactlessly solely using the measuring signals obtained with the multifrequency eddy current sensor 4.

Before the obtained measuring signals, which are present as amplitude and phase data, can be assigned to exact width values b, for example by giving absolute mm values, the measuring signals must be calibrated, which according to the present invention, is carried out dynamically, i.e. during normal production conveyance of the to-be-measured planet wheel bolts to the multifrequency eddy current sensor 4. Provided that the partially hardened planet wheel bolts, present as half-finished products, are so-called Okay parts, i.e. planet wheel bolts with correctly dimensioned soft zone widths b, which are known, the first n of the workpieces conveyed to the multifreqeuncy eddy current sensor 4 are selected for calibration. Single planet wheel bolts are measured for calibration purposes in a suited manner, with the planet wheel bolts measured in the aforedescribed manner always yielding the measuring signals which are correlated with the absolute soft zones widths b. In order to, for example, extract the measuring signal which represents the soft zone width b adjacent to the left front end of the planet wheel bolt 1 from the amplitude locus curve, the point P1 is selected based on the empirically gained data. The number of the measuring signals lying between the point P1 and the minimum is determined empirically. Selection of the point P2 which represents the width of the right soft zone occurs in the same manner.

However, determining a calibration curve requires, at least one additional measuring point yielded by detecting a measuring signal in the center of the planet wheel bolt, thus in the center of the hardened zone 2. This measuring signal P3 is located between the minimum and the maximum of the amplitude locus curve. As it can be assumed with certainty that this region contains no soft areas, the soft zone width b equals zero. Based on these two measuring values, a calibration curve is plotted,

which is used as a basis for further measurement of the subsequent planet wheel bolts.

All the planet wheel bolts following in conveyance direction the planet wheel bolts already measured for calibration purposes are measured with regard to their soft zone widths b in the identical manner, however on the basis of the obtained calibration curve. This is done by assigning the measuring signals obtained on the defined measurement constellations to the width values regarding the soft zone 3 which can be obtained from the calibration curve.

In order to further increase measurement precision, the planet wheel bolts used for calibration purposes can subsequently be measured regarding their respective soft zone widths b using conventional measuring methods. If the conventional measuring methods, for example visual measurement of the soft zone width of etched bolts, in which the soft zone differs distinctly in color from the hardened zone, deviate from the measuring signal obtained by means of the dynamic calibration, the calibrated curve can be corrected accordingly.

With the aid of the invented method, planet wheel bolts can be conveyed along a conveyance path to a multifrequency eddy current sensor in such a manner that it is possible to measure precisely up to 60 planet wheel bolts a minute. The measurements can be conducted with a quantitative precision of ± 0.3 mm regarding the width value of the soft zone. This extraordinarily high precision and reliability of the testing method results in a very low pseudo-reject rate, which gives the part of the measured planet wheel bolts which were erroneously evaluated outside a freely selectable tolerance range.

List of References

1 planet wheel bolt

2 hardened zone

3 soft zone

4 multifrequency eddy current sensor